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Multi-Hundred Kilowatt Roll Ring Assembly Evaluation Results

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MULTI-HUNDRED KILOWATT ROLL RING ASSEMBLY EVALUATION RESULTS

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ABSTRACT

NASA Lewis Research Center has been evaluating low loss multi-hundred-kilowatt Roll Ring assemblies (an eight circuit and a four circuit) for use on Space Station as the rotating joint power transfer device. In this device ac or dc power is transferred across the rotating joint through compressed rotating flexures. Results and conclusions of the evaluation program will be presented.

INTRODUCTION

The Roll Ring concept transfers power (ac or dc) across a rotating joint through slightly compressed multiple rotating flexures connecting the inner and outer conducting rings as shown in Fig. 1. The rotating flexures eliminate virtually all of the sliding friction allowing the Roll Ring assemblies to be rotated with very low torques. A multi-hundred kilowatt Roll Ring assembly employs (10) multiple flexures per ring to distribute the current and provide redundant current paths.

The NASA Lewis Research Center has been evaluating multi-hundred kilowatt Roll Ring assemblies developed by Sperry Corporation - Flight System Division since March, 1985 (1). The multi-hundred kilowatt Roll Ring assembly was selected as one of the best one hundred new products of 1985 and received an IR-100 award from Research and Development magazine.

Roll Ring Assembly Description

The 400-kW Roll Ring assembly (Fig. 2) consists of eight power rings that make up four 200 A-500 volt circuits. The 200-kW Roll Ring assembly (Fig. 3) consists of four power rings that make up two 200 A-500 volt circuits.

Each power ring has ten slightly compressed gold plated Beryllium Copper flexures which rotate between two gold plated conducting rings. Each flexure is designed to carry 20 A of current. To prevent cold welding in space the gold plating on the flexures is of a different alloy than the gold plating on the conducting rings. The flexures are separated from each other by rotating idlers (Fig. 1). Figure 4 shows how the flexure fits into the groove of the inner and outer conducting rings. If there is a small misalignment between the inner and outer conducting ring, the contact points of the flexures move up or down on the conducting surfaces of the conducting rings causing no loss of performance. As the power is transferred across the rotating flexures virtually all sliding friction has been eliminated, as a result the torque to turn the Roll Ring assemblies is very low (approximately 40 in.-oz) for the 8-circuit assembly.

Testing

Thermal equalibrium and accelerated life testing of the 8-circuit and 4-circuit Roll Ring assemblies was performed in a bell jar test facility (Fig. 5). Figure 6 shows the 8-circuit Roll Ring assembly mounted onto the temperature control plate of the test rig. The Roll Ring assemblies were driven with a stepper motor capable of driving assemblies at 16 r/day (actual space station speed) and 5 rpm. The 5 rpm speed was used for accelerated life time testing. The Roll Ring assemblies were also corona tested in air using a Biddle corona tester.

Thermal Equalibrium Testing (8-Circuit Roll Ring Assembly)

Thermal equalibrium testing was done at 50, 100, and 150 A in the test facility shown in Fig. 5. The Roll Ring assembly had thermocouples mounted on the top, on all terminals, and on the 50 °C temperature controlled base plate. The equalibrium temperature profiles are shown in Fig. 7. It should be noted that in this test the rotor had no direct thermal path to the 50 °C base plate. The only thermal paths from the rotor were through the flexures to the stator and through the bearing. There is no equalibrium profile for the 200-A test because the assembly bound up before equilibrium was reached. It was determined that a 70 °F difference across the bearing caused a high enough preload on the bearing to stall the assembly.

This is a bearing problem, not a Roll Ring problem. The profiles show that the terminals that go to the base plate (terminals 1, 4, 5, and 8) are considerably lower in temperature than the terminals that do not go to the baseplate. On the Space Station the Roll Ring assembly will run at lower temperatures than the profiles because the rotor will have better thermal paths to its case and mounting bracket; also the cables will conduct heat away from the unit. The dashed lines on Fig. 7 show the projected temperature profiles of the Space Station current for the initial 75-kW power system and the 300-kW growth station (37.5-kW initial and 150-kW growth per assembly).

Accelerated Life Testing (100 A)

Both Roll Ring assemblies were operated in the vacuum test facility at 5 rpm with 100 A of dc current to achieve many equivalent years of Space Station rolling time. Since the Roll Ring assemblies have no lubricant, the only wear mechanism is rolling friction. The voltage drop across the terminals was monitored along with the number revolutions. The 8-circuit Roll Ring assembly completed more than 60 yr of Space Station rolling time with an average efficiency of 99.98 percent and the 4-circuit Roll Ring assembly completed more than 114 yr of Space Station rolling time with an average efficiency of 99.97 percent. Table I shows the efficiency and life results of the testing.

High Voltage Testing (500 V dc and 440 V-20 kHz)

The 8-circuit Roll Ring assembly was tested at 500 V dc-10 A in the vacuum test facility with a vacuum of 1.0×10^{-4} Torr or less for approximately six months. The Roll Ring assembly was turning at either 5 rpm and 16 r/day during this test. Approximately 3.3 yr of rolling time was added to the assembly during this test. No problems occurred during this test. The unit was corona checked at the end of this test (see corona testing for results). The 4-circuit Roll Ring assembly was modified after the life tests and placed in the vacuum test facility for 440 V-20 kHz-1.5 A life test. With a vacuum of 1.0×10^{-4} Torr or less, the assembly has been under test since September 21, 1987. The test is still being run. There have been no problems with the Roll Ring assembly and the life test will be continued for the next few years. The first part of the test was run at 5 rpm and accumulated 22 yr of Space Station rolling time and then the speed was reduced to 16 r/day. Before and during this test, the 4-circuit Roll Ring assembly was corona checked in air to see if there was any change in the corona onset levels. The results of these tests are reported in the corona test section of this report.

Corona Testing

The 8-circuit Roll Ring assembly was corona checked after the temperature equalibrium tests and the high voltage tests were completed. It was found that the on-set voltage levels ranged from 450 to 1800 V as measured with a Biddle corona tester using the 60-Hz test mode. When the Roll Ring assembly was disassembled and inspected, it was found that an arc starting from an exposed thread on a power stud had traveled over a insulator plate to ground. Apparently a carbon track was created on the insulator disk when the unit was accidently pumped down with 500 V dc applied to the assembly. Severe arcing occured during this pump down and some damaged parts had to be replaced.

As the insulator disk was not replaced the carbon track was probably formed at that time. The parts were washed with alcohol and reassembled. The low corona onset level went from 450 to 625 V after cleaning. The design problems found in the 8-circuit Roll Ring assembly (exposed threads and direct line of sight between charged surfaces) were corrected in the redesign of the 4-circuit Roll Ring assembly. The resulting increase in the corona breakdown voltages is shown in Table II.

A corona check was performed on the 4-circuit Roll Ring assembly before 100 A vacuum test. Tests showed that the Roll Ring assembly had corona onset voltages ranging from 400 to 650 V with the retaining top lid on the assembly and 650 V for all circuits with the retaining lid off (Table II). It was found that arcing occurred through a gap in an insolator ring that separated the circuits (Fig. 8). Also when the retaining lid was in place, there was a large surface area of an insolator disk on the retaining lid which trapped a thin layer of air between them. This thin layer of air breaking down caused the low corona onset voltage with the retaining lid in place. The 4-circuit Roll Ring assembly was modified after the 100 A accelerated life test to incorporate all the changes needed to correct the corona problems, including the design changes that were discovered during testing of the 8-circuit Roll Ring assembly. Also extra vent holes were added to enhance outgassing of the assembly. The unit was corona checked after the modifications were completed and the voltages ranged from 800 to 1180 V. The unit was corona checked after six months of 440 V-20 kHz testing and the corona on set values increased significantly. The corona on set values increased up to a maximum of 1650 V as shown in Table II. This improvement was attributed to rolling in the assemlby. The unit will be periodically corona checked during the 20 kHz vacuum test.

High Power Test (52.5A - 440 V - 20 kHz

A high power bench test was conducted to determine the voltage drop across one circuit of the 4-circuit Roll Ring assembly. A voltage drop of 563 mV or 0.0014 percent was measured when there was 52.5 A flowing with 420 V-20 kHz applied. It should be noted that most of this voltage drop is reactive and does not contribute to a heat loss in the assembly. If inductance of the single circuit is calculated using the dc resistance (0.45 mΩ) instead of the ac resistance (not known) the worst case inductance value is obtained. The inductance calculated was 0.08 micro-H per circuit which compares to the 20 kHz cable inductance of 0.032 micro-H/m. As the actual value of the circuit inductance is probably very close to the cable per meter inductance values. The Roll Ring is electrically equivalent to about one additional meter of cable.

CONCLUSIONS

The Roll Ring assemblies have proven to be very rugged rotary power transfer devices that can transfer hundreds of kilowatts at high efficiencies (greater than 99.9 percent). The Roll Ring assemblies have been tested in air and vacuum (both dc and 20 kHz ac) and have achieved over 180 yr of Space Station rolling time with no major problems. The corona tests identified some design areas requiring correction to increase the corona onset voltage. When these design changes were incorporated in the modified 4-circuit Roll Ring assembly tests verified that the corona onset voltages were increased. The Roll Ring is inherently redundant

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were incorporated in the modified 4-circuit Roll Ring assembly tests verified that the corona onset voltages were increased. The Roll Ring is inherently redundant because of the multiple flexures (ten per ring). Since sliding friction is virtually eliminated, the Roll Ring assembly requires very little torque to be rotated. Due to the design of the flexure and conducting rings, the Roll Ring assemblies can withstand some misalignment and still function as designed.

REFERENCE

1. Jacobson, P.E., 1985, "Multi-Hundred Kilowatt Roll Ring Assembly," NASA CR-174832.

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TABLE I. - LIFE TIME (ROLLING SPACE STATION YEARS) AND AVERAGE EFFICIENCY

[All data was taken with 100 A of dc current.]

8-Circuit Roll Ring assembly		4-Circuit Roll Ring assembly	
Rolling SS., years	Efficiency	Rolling SS., years	Efficiency
20	99.995	20	99.977
40	99.987	40	99.970
60	99.987	60	99.975
--	------	80	99.974
--	------	100	99.966
--	------	114	99.966

TABLE II. - ROLL RING ASSEMBLIES CORONA ONSET VALUES

8-Circuit Roll Ring assembly				4-Circuit Roll Ring assembly				
Terminal	Test			Terminal	Test			
	a_1	b_2	c_3, V		d_1, V	e_2, V	f_3, V	g_4, V
1	450 V	900 V	625	1	650	400	800	1250
2	900 V	1.2 KV	700	2	↓	425	1180	1180
3	1 KV	1.8 KV	1275	3	↓	650	1000	1620
4	550 V	↓	950	4	↓	650	1000	1650
5	1800 V	↓	1700	-	---	---	----	----
6	↓	↓	1400	-	---	---	----	----
7	↓	↓	1600	-	---	---	----	----
8	↓	↓	1500	-	---	---	----	----

[a]Run with lid on after all life time tests.
[b]Cleaned parts with alcohol and had lid off.
[c]Cleaned parts with lid on.
[d]Before life testing, lid off.
[e]Before life testing, lid off.
[f]Modified design before 20 kHz life testing.
[g]Modified design after 6 month life testing.

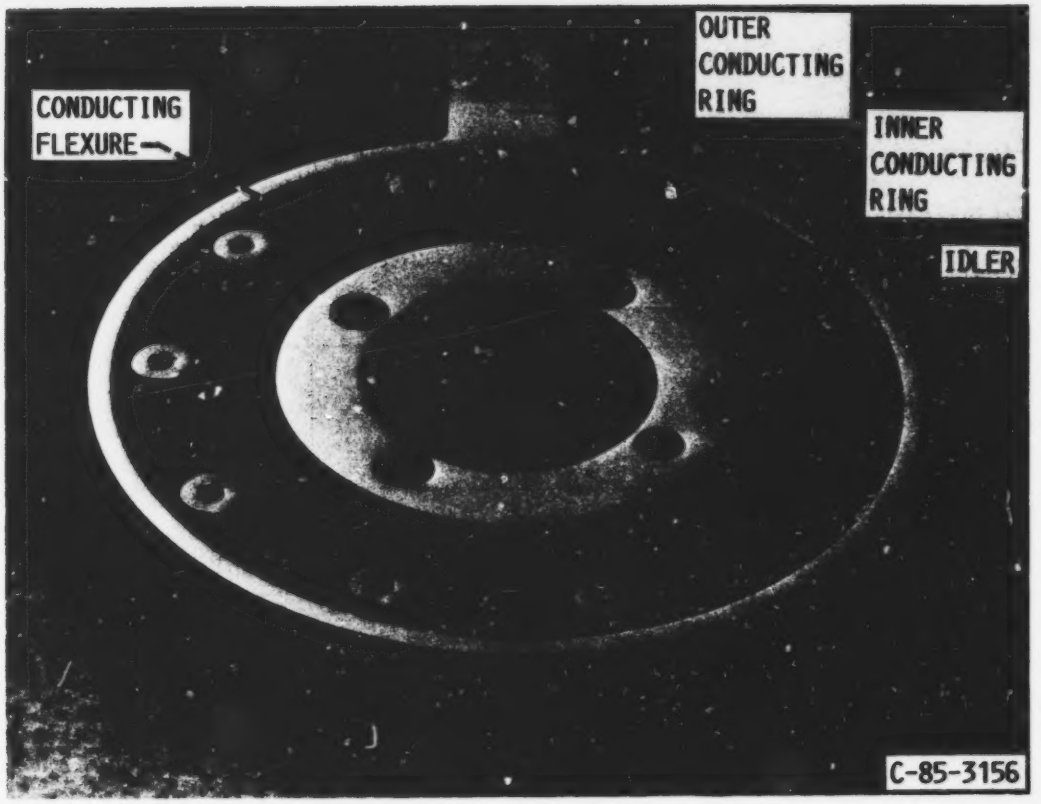

FIGURE 1. - SINGLE ROLL RING CIRCUIT.

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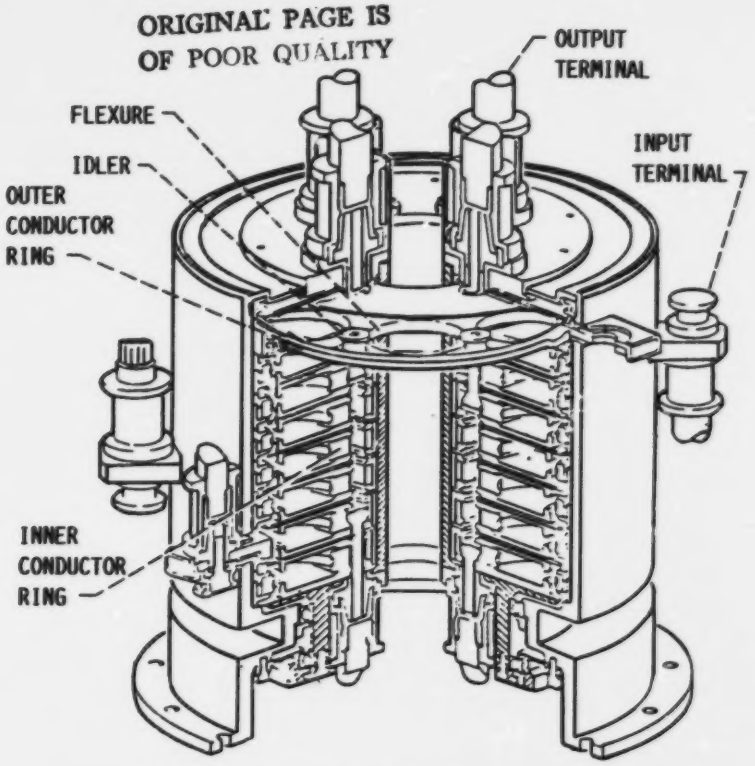

FIGURE 2. - CROSS SECTION OF THE 8-CIRCUIT ROLL RING EVALUATION UNIT.

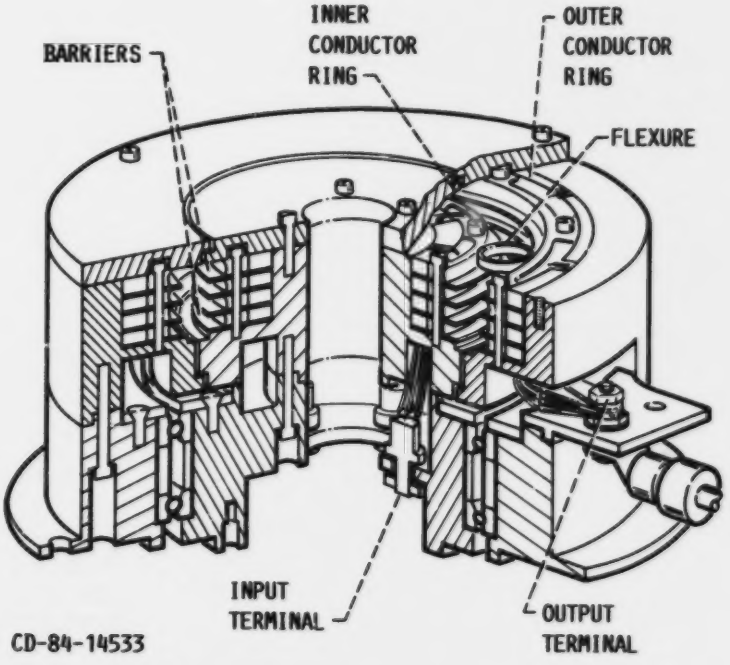

FIGURE 3. - FOUR CIRCUIT ROLL RING ASSEMBLY.

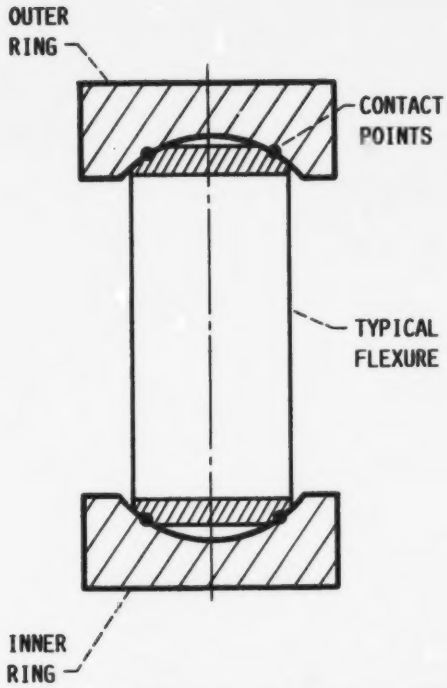

FIGURE 4. - FLEXURE/RING GROOVE GEOMETRICS.

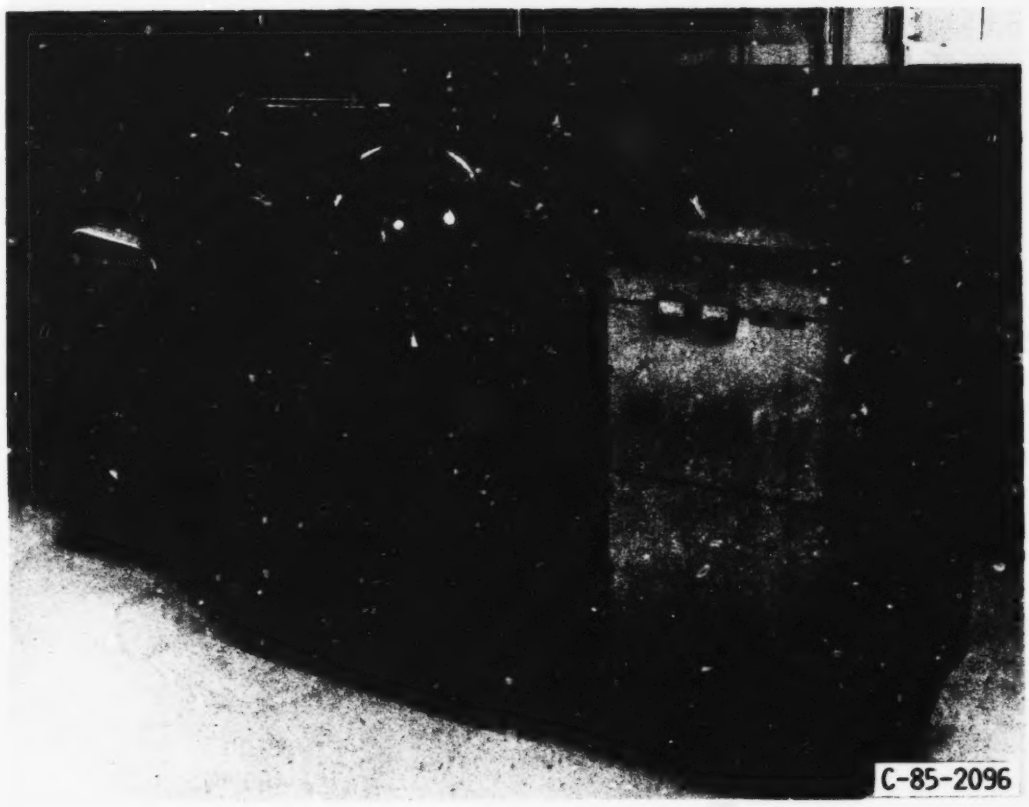

FIGURE 5. - VACUUM TEST FACILITY.

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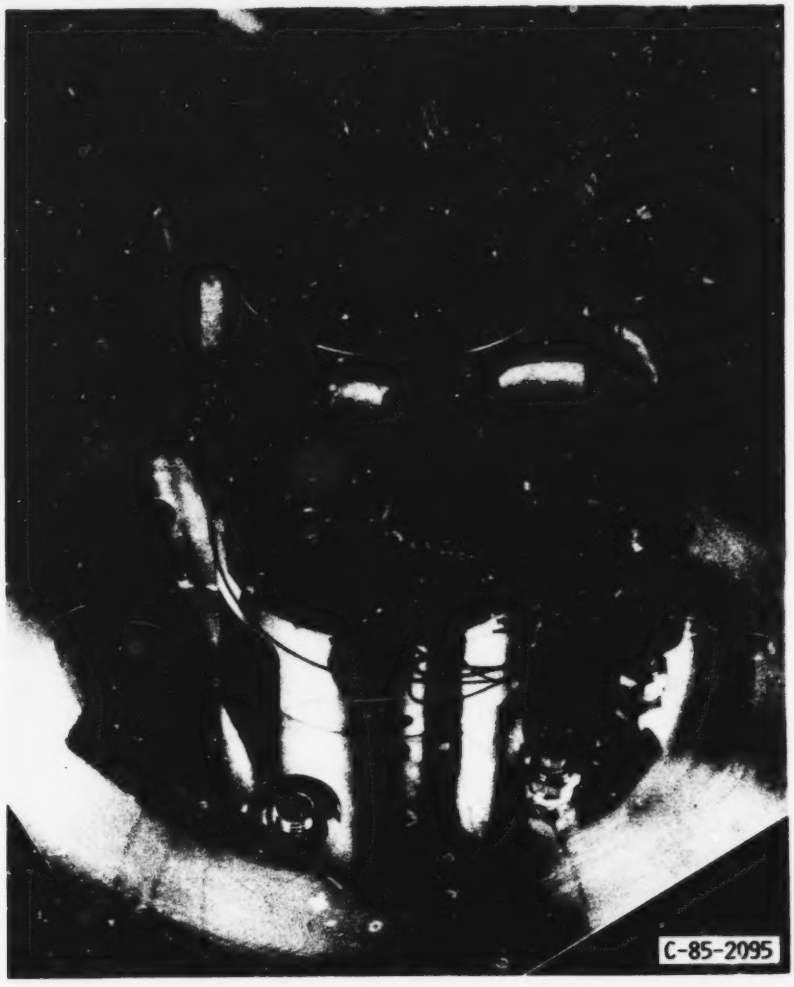

FIGURE 6. - 8-CIRCUIT ROLL RING ASSEMBLY.

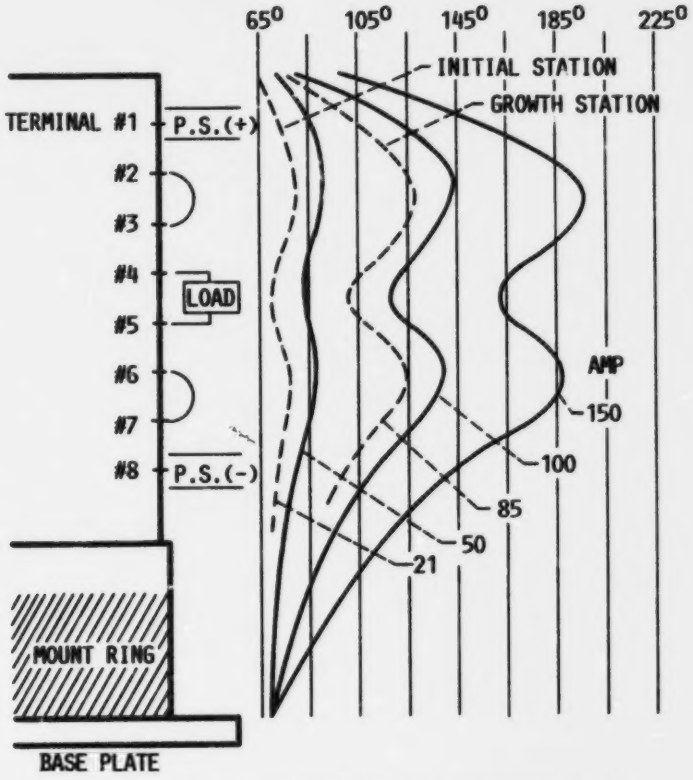

FIGURE 7. - ROLL RING EQUILIBRIUM TEMPERATURES, °F.

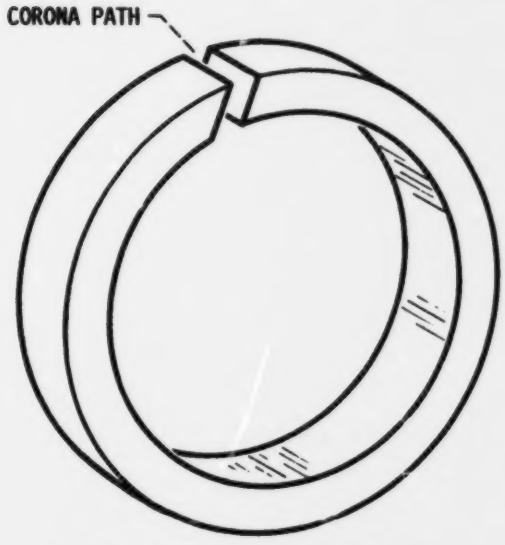

FIGURE 8. - SPLIT ISOLATOR RING.

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16. Abstract

NASA Lewis Research Center has been evaluating low loss multi-hundred-kilowatt Roll Ring assemblies (an eight circuit and a four circuit) for use on Space Station as the rotating joint power transfer device. In this device ac or dc power is transferred across the rotating joint through compressed rotating flexures. Results and conclusions of the evaluation program will be presented.

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